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The DoD HPCMP CREATE program is developing and deploying multi-physics High Performance Computing (HPC) software applications for engineers to design and make accurate predictions of the performance of military air craft, ships, ground vehicles and radio frequency antennas. When CREATE started (~2007), there was no commonly recognized set of successful software project management practices for the development of multi-physics, HPC engineering software. Based on lessons-learned from the HPC and computational engineering community, the CREATE leadership developed and implemented a risk-based, practice-centered strategy to organize and manage the highly-distributed CREATE program.

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A Risk-based, Practice-centered Approach to Project Management for HPCMP CREATE

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DoD High Performance Computing Modernization Program (HPCMP)

Abstract
The DoD HPCMP CREATE program is developing and deploying multi-physics High Performance Computing (HPC) software applications for engineers to design and make accurate predictions of the performance of military air craft, ships, ground vehicles and radio frequency antennas. When CREATE started (~2007), there was no commonly recognized set of successful software project management practices for the development of multi-physics, HPC engineering software. Based on lessons-learned from the HPC and computational engineering community, the CREATE leadership developed and implemented a risk-based, practice-centered strategy to organize and manage the highly-distributed CREATE program. This approach led to a good balance between ensuring a sufficiently structured workflow and accountability and providing the flexibility and agility necessary to create new sets of engineering tools with the capabilities needed to design next-generation weapon systems.

Introduction
The Department of Defense (DoD) High Performance Computing Modernization Program (HPCMP) Computational Research and Engineering Acquisition Tools and Environments (CREATE) Program, described in the CREATE program Overview[1], is developing and deploying thirteen physics-based high performance computing applications to DoD engineers to make accurate predictions of the performance of military aircraft, ships, radio frequency antennas, and ground vehicles. These predictions are designed to reduce the risks, costs, and time to develop and deploy these weapon systems, and improve their performance. Using the CREATE tools, DoD engineers are able to construct and test virtual prototypes of weapon systems. This enables them to identify and fix design flaws and performance shortfalls early in the acquisition process, well before live tests are possible and "metal has been cut." Experiences in industry and other federal agencies demonstrated that use of this paradigm can reduce costly rework and result in reduced risks, costs, and time to deployment as well as improve product performance and quality[2, 3].

This paper describes the practices that were developed and implemented over the past nine years to manage the key CREATE risks that confronted the CREATE program. The CREATE tools are based on many years of scientific and engineering research that has been instantiated in software in "research" codes. The challenge is to turn this knowledge into engineering software that can confidently be used by engineers who didn't develop the software. The risk is that the software won't be sufficiently robust and usable for the engineering community. Many, if not most, such projects have failed in the past e.g. [4].

Our experience and the recommendations in the program management literature e.g. [5] are that all successful programs have three simple but essential elements: 1) a program vision that identifies the program benefit and goals that define the requirements; 2) a strategy

that is expressed in plans and processes for execution; and 3) the resources required to execute the program including stable funding, a well-led team with the requisite technical and project skill set, and the necessary infrastructure and institutional support. Success requires all three elements be adapted to fit the specific program environment and constraints (the DoD in the case of CREATE).

These CREATE practices are based on a set of key principles (Table 1) that incorporate these key elements and are designed to reduce those risks. These principles are based on: 1) the authors' collective professional experiences and "lessons learned" over their careers; 2) published case studies of similar projects; 3) the software project management literature and training courses taken by the authors, and 4) successful practices for commercial, multi-national product development and adoption supporting 30,000 software installations. None of these principles are surprising. Many of them are in the standard literature[6] or appear in the Agile Manifesto (www.**agilemanifesto**.org). However, relatively few science-based software projects have explicitly implemented them.

Table 1: Software Project Management Principles (Lessons-Learned)

- Develop a compelling and credible vision and be able to communicate it.
  — *Without a compelling, credible vision, it won't be possible to obtain initial funding or to defend the program*
- Develop a long term strategic plan and define the essential processes required to execute it
  — *A long term plan is essential for guiding the development of shorter-term, more detailed plans, and processes are required to execute the program*
- Balance the need for an agile development process that empowers the development team with the need for accountability and an organized development process
  — *The development teams need to have the freedom to exercise their technical judgment, but also need to produce a product*
- Recognize that the role of program management is to provide:
  o Program Leadership beyond merely Program Management
  o Stable funding, hosting, and stakeholder support and a constructive development and deployment environment,
  o Guidance for solving organizational and technical problems, and
  o Support to solve institutional problems the development team is unable to solve
  — *The Program Leadership needs to shield the development team from institutional turmoil and other distractions as much as possible*
- Recognize that the role of the development team is to provide high quality software applications within schedule and budget
  — *The development team needs to understand its responsibility to develop and deploy the software*
- Emphasize the central and essential roles of the development team and its leadership
  — *Teams develop software. Organizations and processes don't develop software*
- Implement a rigorous verification and validation program
  — *Without a good V&V program, your codes won't be credible*
- Identify the challenges for developing and deploying the software within your organization and customer base
  — *The Program management must help the team meet those challenges*

CREATE employs thirteen distributed multi-disciplinary non-collocated teams centered at eight separate Department of Defense (DoD) sites and led by a Program Office located at the HPCMP office in Lorton, VA. The CREATE personnel are a mixture of government civil servants and defense contractor support scientists, engineers and consultants. These personnel are located at 29 dispersed sites. The support contractors are drawn from 25 separate contractor organizations. CREATE's highly distributed development organization illustrates merely one of the five "complexities" (Table 2) that CREATE has had to address since its inception in 2006.

Table 2—Five Complexities Specific to the DoD

- Complex program management challenges (i.e. development of new, innovative, risky, state-of-the-art (and beyond) computational technologies in DoD organizations that rigorously adhere to DoD program and project management processes).
- Complex development environment (distributed, multi-disciplinary teams across multiple sites and embedded in Army, Navy, and Air Force organizations).
- Complex engineering applications (integrated multi-scale, multi-physics—e.g., computational fluid dynamics, structural dynamics, turbo-machinery, electromagnetics, etc.)
- Complex computing environments (networks; cyber security; rapidly evolving computer architectures,…)
- Complex customer organizations: Army, Navy, Air Force, and defense industry acquisition engineering organizations; the DoD research, development, testing and evaluation [RDT&E] communities; and the DoD HPCMP.

Establishing, managing and leading software development in the presence of these "complexities" poses many Project Management challenges, some unique to the DoD, but many that are common to all distributed physics-based software development and deployment projects. This paper describes the Program Management approach taken by CREATE Program Office to develop and deploy high-quality, robust engineering HPC software in the face of these complexities.

Sound and effective software engineering practices are key elements for success. Those detailed practices, including verification and validation, code development methodologies, program execution issues, etc., will be described in detail in subsequent papers.

CREATE Program Core Risks

The initial development and deployment of the CREATE program was planned to take twelve years. The experience of projects of similar complexity and scope is that it takes that long to develop, validate and deploy the software to the point that the tools can demonstrate sufficient value to warrant continued support [7, 8]. This estimate is consistent with the history of the CREATE projects (now completing their eighth year). Successful engineering software applications that have proved their value can have lifetimes of 30 to 40 years (e.g. 50 years in the case of NASTRAN, http://www.mscsoftware.com/product/msc-nastran), so that it is probable that the CREATE tools can have a long, useful life if their development and support continues.

Each of the five "complexities" of CREATE is a source of risk and uncertainty. Software development is universally a risky undertaking and failure is common and widespread. Going back decades, numerous authors have described the sources of software development risk (e.g., Boehm[9] or DeMarco[10]). CREATE is no different. The Software Engineering Institute (SEI) published a risk taxonomy for scientific and engineering software[11] that organizes the sources of risk around the:

- Software development cycle
- Development environment
- Programmatic environment

The CREATE program software management approach included many insights gained from the Department of Energy's ASCI Program [7] and other studies sponsored by the Defense Advanced Research Projects Agency (DARPA) High-Productivity Computing Systems Program (HPCS)[12].

At the outset, the CREATE program identified ten core Program-level risks (Table 3) in the DoD environment that it would have to address. Of course, the software development cycle and environment also present risks, but this paper will focus on programmatic risk leaving the former to subsequent papers. We have found that programmatic risks are the most difficult to manage because their sources are often very difficult to influence from within the Program. The other two sources of risk can largely be mitigated by the adoption of sound software engineering practices tailored for projects like CREATE.

The specific program management practices described in this paper were developed by applying the Software Program Management Principles (Table 1) to manage the programmatic risks described below. There is no implied priority in the listing below. At various times of the life of CREATE, numbers 4. And 5. have been paramount; at other times 8. has been the greatest concern. Increasingly, 9. And 10. are important concerns as the CREATE products mature.

Table 3: Ten Core Program-level Risks for CREATE

1. Inability to meet the challenge of creating and inventing new, innovative software technologies within the existing DoD program and project management structure.
2. Loss of Credibility and Effectiveness due to defects or insufficiently accurate models in the software that would result in inaccurate results
3. Inability to build and manage software development teams because the CREATE program relies on sponsoring development teams embedded in and part of the relevant DoD customer organizations.
4. Significant losses of core development staff and their corporate knowledge due to severe funding reductions and other institutional turmoil
5. Inability to ensure program coordination within the diverse management cultures— including security management—within different DoD organizations.
6. Inability to manage requirements creep and relevancy over the major development phases of the project

7. Inability to anticipate and respond to the impact of rapidly changing computational and computer technologies (especially rapidly changing computer architectures and environments).
8. Loss of DoD stakeholder and sponsor support due to frequent turnover of senior DoD personnel.
9. Loss of Control of Intellectual Property Rights.
10. Inability to support CREATE software users

The Management of Risk through Practices

The distributed nature of the sponsorship, customer base, and likely workforce of CREATE – directly reflected in several of the core risks—posed a major program management challenge. DoD programs in the past have utilized "strong, highly centralized program management with well defined, detailed processes" for large, complex programs. CREATE is complex, encompassing distributed teams located at many DoD and DoD contractor locations composed of ~ 135 government and contractor staff. The teams face major technical challenges to build and deploy the software. However CREATE is much smaller than most DoD acquisition programs and thus is unable to have much influence on DoD policies and procedures. Our experience indicates that process-heavy program management approaches have been less successful for software development projects like CREATE than practice-driven approaches[4, 13]. The imposition of a strong focus on processes runs the risk of alienating and disempowering technical software development staff who are essential to the success of CREATE. Moreover, the different cultures of the Army, Navy and Air Force, the home organizations of most of the CREATE personnel, and the highly distributed nature of the development teams rendered the adoption of a monolithic, prescriptive, process-driven management approach infeasible. Instead, we adopted practices modified appropriately to be effective for environment of each development team.

The practices we present here were present, if only implicitly, in many of the successful components of the ASCI (DOE) and HPCS (DARPA) programs cited above. They are consistent with the intent of milestone-based, process-oriented approaches like the Software Engineering Institute's Capability Maturity Model [14]. [see www.sei.cmu.edu/cmmi/]. The CREATE team adopted practices synthesized from the DoD Federal Acquisition Regulations to ensure compliance with DoD regulations. The remainder of this paper will illustrate the connection between the practices of CREATE and the risks they mitigate for the DoD environment.

Risk 1. Inability to meet the challenge of creating and inventing new, innovative software technologies within the existing DoD program management structure.

The Department of Defense is a very large, military organization (~ 3 Million employees) with a large budget (~$600B). It operates by requiring adherence to a uniform set of processes and regulations that apply to the DoD civilian workforce as well as military staff [15].
Somewhat in contrast, the development of new technical software for the design of highly innovative weapon systems by the DoD acquisition engineering community is a "creative" process. It involves the invention of something that is new and innovative,

something that cannot be produced by following a rigid, detailed, repetitive process. Success requires experimentation, taking risks with the possibility of failure, and "learning by doing". It is not a repeatable process. CREATE developed a program management approach that satisfies DoD needs, but is able to provide the necessary agility and flexibility for the development teams to be innovative and take the risks necessary to succeed. Many DoD-recommended management practices are designed for very large programs, and are not needed for the management of relatively small code development teams. We found that many typical DoD processes such as: highly detailed, multi-year plans; Earned Value Management; detailed requirements lists; elaborate requirements tracing methods; detailed oversight with frequent formal project reviews; and extensive reporting processes are not applicable or effective for the CREATE development process. Earned Value Management (EVM), for instance, is a standard practice within DoD. To be successfully applied, EVM depends on timely and accurate cost accounting and level-of-effort data. For CREATE, it was not possible to collect this data in a timely way across the Program due to the differences in the Service's accounting systems. The EVM process itself also had to be tailored to the flexible execution of workflow tasks characteristic of agile software development methods.

Practice: Adopt a program management approach that:
- *Encourages the use of agile software development methodologies[6] (e.g. Scrum[16]) and flexible planning;*
- *Emphasizes leadership in contrast to management;*
- *Supports and facilitates the success of the development teams but also instills a sense of accountability and encourages an organized code development process.*
- *Resist the imposition of bureaucratic processes that do not add value to the code development process.*

Risk 2. Loss of Credibility and Effectiveness due to defects or insufficiently accurate models in the software that would result in inaccurate results

The purpose of the CREATE software is to enable DoD engineers to accurately predict the performance of DoD weapon systems. Errors (either defects or insufficiently accurate or inappropriate models or misuse of the tools) that lead to incorrect results destroy the value of the codes. Incorrect results waste resources, discredit the CREATE tools, and could ultimately cause injury and death and lead to the demise of the CREATE Program.

Practice: Require Extensive Validation and Verification (V&V) Testing of the CREATE tools and Quantification of the Uncertainties of the Code Results

An extensive and effective verification and validation program is essential for ensuring that the tools provide accurate answers. The CREATE codes employ a rigorous verification and validation effort, based on best practices identified by its founders in programs like ASCI[7] and HPCS[17]. Recently the National Academy of Sciences has published guidelines for the testing of scientific and engineering software[18]. CREATE testing practices generally already conformed to these guidelines. The CREATE V&V practices and other detailed software engineering practices will be described in a subsequent paper. The CREATE tools develop decision data for acquisition programs. Accurate estimates for the uncertainties in the data are essential for making sound decisions based on that data.

Risk 3. Inability to build software development teams because the CREATE program has no authority to hire staff.

The DoD funded the CREATE Program but didn't assign any personnel slots to the program. A number of staffing options were considered including giving the lead responsibility to a private contractor, a DOE national laboratory, a DoD University Affiliated Research Center, or one of the service laboratories. The DoD needed to retain "ownership" of the software. While the relevant subject matter expertise has always resided in the DoD customer organizations, few of them have been able to secure sustained funding for code development; nor did many of them have much experience developing high quality multi-physics-based high performance computing engineering software that is usable, sustainable, maintainable, extensible and portable. The final choice was for the HPCMP to build code development teams around subject matter experts within the DoD acquisition engineering organizations such as the Naval Surface Warfare Center, Carderock Division—the Navy organization responsible for ship design tools and assessments. The HPCMP was able to assemble a team of senior leaders with successful experience developing computational engineering software that was able to provide the code development leadership and guidance to the service-led development teams. CREATE sponsored the teams by provided funding, computers, and development services, and active leadership and management of each team's code development process in collaboration with the relevant service organization. This approach has worked well.

A major advantage of embedding the teams in the customer organizations is that transition of the codes to the customer engineering organizations is compellingly straightforward. The design engineers who use the codes are part of the organization that developed the codes. That ensures a level of trust and ease of adoption that is difficult to obtain for externally developed codes. It eliminates many of the barriers that often inhibit adoption of new technologies by the DoD acquisition community.

Practice: Identify a principal developer within the customer organization (in this case, one of the Armed Services) around whom one can build a team.

Each of the technology areas targeted by CREATE had native champions within specific customer (Service) organizations. Moreover, many of the champions had been instrumental in the initial development of the CREATE program proposal and were familiar with the technical and management challenges. It was straight-forward in many cases to recruit a team leader acceptable to both the CREATE Leadership and to the relevant Service host organization. In other cases, a lengthy search process was necessary. Our experience is that the selection of the right team leader is the most important decision affecting the success of the project. In several cases, we had to try two or three team leaders before finding the right person. Recruiting a team within a customer organization to develop tools for which the need was already recognized by the organization turned out to be feasible with the addition of CREATE funding and oversight. A team leader must be able to recruit and retain talented team members. Long-term engineering software development projects like CREATE are very risky. As noted before, many such projects have not had successful outcomes[19]. Prospective CREATE team members need to believe that there is enough potential for

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success to invest five or ten years of their careers in the project. Professional and personal respect for the team leader is essential for recruiting team members to take that risk.

In addition, a team leader who is a valued senior staff member of the customer organization has the professional and technical trust of the leadership of that organization. As noted before, this greatly facilitates adoption of the code by that organization and similar organizations. For instance, the lead developer of the Ships hydrodynamic code leads the computational fluid dynamics effort at the Naval Surface Warfare Center responsible for surface ship design.

Practice: Employ lean (5-15 person) development teams led by technical experts.

While it might appear that "multi-physics" implies large teams, CREATE chose to use small, distributed teams. In our experience a close-knit team founded on trust and able to communicate effectively within the team is the most important success factor for development of complex, large-scale physics-based software. Trust and communication is most easily established within a small team (5-15 people) of highly competent staff, especially if the team is not collocated (as is the case for almost all of the CREATE Projects). Moreover, large development teams inevitably require more management overhead and process than small teams. The scarcity of staff with different sets of required highly specialized technical skills necessitated enlisting team members across two or three sites, or more.

Sound technical judgment, especially for the team leader, has been a crucial success factor for the achievement of CREATE's technical goals. A good team leader needs a solid grounding in the relevant science/engineering fields and must have experience in and knowledge of computational science and engineering. The leader must possess effective interpersonal and leadership skills needed to organize, lead, and inspire a team, and be able to manage the project and its finances.

It's impossible to overstate the importance of the code development team and its leader. The team develops the software. The major task of a software development organization and its management is to support the team and the team leader. The quality of the team and the team lead is the best predictor for the success of the project. With the right team leader and the right team, there is a good chance of success. The wrong team leader dooms the project. As Tom DeMarco puts it in his novel on Software Project Management [20]:

> "Get the right people.
>   Match them to the right jobs.
>   Keep them motivated.
>   Help their teams to jell and stay jelled.
>   (All the rest is administrivia.)"
>   —T. DeMarco[20]

At the Program Office level, CREATE recruited a diverse set of technical expert consultants to augment support of management issues like software engineering, acquisition processes, customer development, IP management, security issues such as export control, etc.

Risk 4. Significant losses of core development staff and their corporate knowledge due to severe funding reductions

By far the most important asset of the CREATE Program is its development staff. It takes a long time and a lot of effort to recruit a good team and a lot of time for the team to jell to establish the trust and working relationships necessary for productive code development. To maintain steady progress, a stable code development team and development environment is essential. That, in turn, requires a stable funding base over multiple years. Large funding oscillations almost always depress morale, and often lead to high turnover rates and permanent loss of essential staff. This greatly increases the likelihood of project failure. The external market for talented, highly motivated software engineers and subject matter engineers with computer skills is very competitive. The CREATE staff have many attractive career options, almost always at higher salaries and with more attractive working conditions. They are working on CREATE because they enjoy the work, and have the opportunity to make a major contribution to the success of DoD acquisition programs.

From the viewpoint of the development staff, significant withdrawals of project funding are interpreted as a lack of confidence in the project and its viability, and a signal they should start looking for other employment. Members of the development teams make a commitment to spend years working on a project that will take years to show progress. They expect a reciprocal commitment, even if implicit, that they will be supported to make the project a success. Nonetheless, the reality is that funding levels do fluctuate, and must be accommodated to minimize the negative impact on the project. CREATE has adopted the following practices to allow it to react thoughtfully to funding fluctuations:

Practice: Ensure that funding requirements for the proposed deliverables are defined and planned for each budget year during the project/product life cycle and are adjusted throughout the year, as changes occur. Emphasize the importance of stable funding to HPCMP and CREATE stakeholders and to senior DoD leadership.

The goals and high level plan for project deliverables are captured in a long-term roadmap. Every year, a project plan for that year is developed taking into account the goals for product deliverables contained in the long-term roadmap, new requirements generated by the stakeholders, new opportunities due to advances in computational technologies (new solutions techniques and algorithms), and the funding levels available for that year.

Practice: Publish long-term product roadmaps, and update as necessary, but at least annually in detail for the near-term.

Risk 5. Inability to ensure Program Coordination within the Diverse Management Cultures—especially Security Management—within Different DoD Organizations.

As a Tri-Service program, CREATE must be able to work effectively across Service boundaries. Each Armed Service (e.g. Navy) has its own rules, processes and cultures that vary among its components. The variation is stronger between the different Armed Services (e.g. Navy and Army). "Management by Walking-around," scheduled short meetings between the management staff, and frequent, but very short meetings among the development teams are highly recommended by the computer software development literature. However,

achieving this is challenging when development teams are not collocated, and computer security issues inhibit communication and data exchange.

In addition, network and system security controls present challenges throughout the CREATE lifecycle from software development through customer usage. The extremely heterogeneous security enclaves across the Services inhibit the development and usage of CREATE software due to policies preventing client software installation and restrictions on network ports and protocols. Some sites do not allow any form of videoconferencing. These impediments have been mitigated to some extent by using browser-based Software as a Service (SaaS) access to CREATE development repositories, issue tracking, testing, documentation, user forums, and software execution resources that requires no client software installation, thus ameliorating many security concerns.

On several occasions, network access for several code teams was shut down for extended periods (up to two years in one case) due to external security and management issues. That risk required mitigations and workarounds.

Practice: Strongly encourage good communication among team members, especially among non-collocated teams. Provide high quality video conference and teleconference capabilities so that the teams can hold frequent virtual meetings.

The HPCMP Defense Research Engineering Network (DREN) group in the HPCMP established and supports a high definition video conferencing capability with high quality audio that has greatly facilitated communication among and within the development teams and with the CREATE Program Office. It allows a limited amount of "Management by Walking Around," and helps keep the Program Office in touch with the teams.

Participation in professional society meetings is strongly encouraged for career growth and learning about the latest developments in the relevant profession, Unfortunately, the recent DoD restrictions on conference attendance strongly limits this.

Practice: Coordinate and share access to CREATE software and information through a data server that supports the whole CREATE program.

In a program as diverse as CREATE, transparency pays big dividends. Successes (and failures) in one area of CREATE can benefit others. In addition, the application development lifecycle requires basic services: code and documentation repositories, forums, issue tracking, and continuous code integration and testing. Also, debug and testing of multithreaded and multi-process (i.e. OpenMP, MPI) code necessitates access to dedicated supercomputers, storage, and interconnects.

In order to facilitate these development services, the CREATE program has established and operates a community site with virtual machines for the CREATE development and user communities[21]. The CREATE community site provides Multi-Factor Authentication (MFA) and hierarchical authorization for access to CREATE software, documentation, configuration management, agile dashboards, requirements and defect tracking, tutorials and even the CREATE user community through the user forums.

Practice: Establish a method for allowing users to use the CREATE software through a browser on their Army, Navy or Air Force systems.

The Army, Navy, and Air Force limit most of their staff, including engineers, to Windows-based PCs with only Microsoft Office and a browser. This effectively prevents the majority of potential users from gaining access to the CREATE software. The CREATE program and the HPCMP developed a web-based portal capability that allows access to the HPCMP systems through a browser and with Multi-Factor Authentication (MFA) and encrypted access. Engineers with access to the Army, Navy or Air Force networks can single-sign onto the HPCMP supercomputers through their browsers; establish a remote desktop; set up their problem; execute jobs; store the results; visualize and analyze the results in-situ; and download the summary conclusions, including graphics and videos. The HPC Portal integrates various forms of help, community forums, and tutorials with the use of the tools themselves. In this model, the CREATE software is near the large datasets generated by the high performance applications, reducing the network load for transferring data between the client workstation and remote file systems.

Finally, the HPC Portal secures access via several mechanisms, including MFA and application-specific authorization. Since no software is installed on the user workstation, vulnerabilities and system updates are transparently completed on the servers. Identity management leverages DoD credentials such as Common Access Cards (CAC), one-time password (OTP), and OpenID. Security is managed within the DREN, as opposed to every desktop. As a "Software as a Service" (SaaS) implementation, execute-only privileges can be enforced. The HPC portal also facilitates access by defense contractors to the HPCMP computers and CREATE tools. It allows their engineers to gain secure access through both their internal and DOD computer networks.

Risk 6. Inability to manage requirements creep and relevancy over major development phases of the project [~twelve years].

The DoD is competing with the rest of the world to rapidly develop new and more effective military technologies in a fast changing world. As a result, the requirements for the CREATE tools change continually. The CREATE program adopted three practices to address the risk of requirements creep and potential irrelevancy. The first relates to the customer focus needed to ensure relevancy:

Practice: Express customer requirements as "use-cases" in customer-oriented language that stakeholders, customers, and developers can understand.

CREATE requirements were originally defined and are continually reassessed by DoD Service stakeholders and potential customers (users) through representation on the CREATE Project Boards of Directors (one for each Project: Air Vehicles, Ships, RF Antennas, Ground Vehicles, and Meshing and Geometry). In addition, the CREATE teams include many seasoned professionals who follow the world-wide progress in militarily relevant science and technology, including computational science and technology.

The requirements are expressed in sets of use-cases[22] that describe the targeted uses of the CREATE codes in customer and stakeholder language. Use-cases are scenarios that

describe at a minimum: (1) the targeted user, (2) the users' goal(s) in context, (3) minimal functionality or performance targets, and (4) main success scenario(s). Use-cases drive specifications that translate use-cases into software features and quality attributes. This not only aids in developing, describing and testing the developed capability, it also eliminates the need for extensive burdensome and opaque requirements traceability processes and reports.

Practice: Manage code development with a workflow culminating in at least one 'distinguished' release, or 'version' each fiscal year.

Reaching 'closure' with releases addresses one of the main failings of many code development efforts. A long delay between formulating requirements and demonstrating solutions often results in a mismatch between the two and is typically a source of requirements creep. While a detailed development process (work flow) has not been not prescribed by the CREATE Program Office, adaptations of Agile methods like Scrum (www.scrumalliance.org) that include milestones (an annual release is a milestone) have been self-adopted by all of the CREATE development teams.

Agile work flow management methods promote frequent release. Within CREATE code teams, there are typically incremental releases between major annual releases. These are encouraged, and minimize the consequences of the poor project management practice of using corrective maintenance mechanisms for minor adaptive maintenance.

Frequent releases:
- Provide CREATE prototypes for customer testing and input,
- Provide an annual demonstration of progress,
- Allow developers to reach closure on incremental capabilities, and
- Help to mitigate requirements creep.

Together with emphasizing the importance of the team leader, annual releases is one of the most important CREATE program management practices.

Practice: Employ pilot projects to solicit customer reaction and input to feature and attribute implementations.

Pilot projects provide another way to ensure that the development effort aligns with customer needs. Like prototypes—a feature of the Spiral Development Method—pilots allow developers to solicit input for improvements by providing users early access to the codes. But in this case, early access is provided to versions that are "hardened" for customer use, not just trial implementations characteristic of prototypes. Pilots help ensure that the customers can determine the value of the codes in their own workflows. They help developers improve the match of the code with customer workflows, thus avoiding a common failure mode due to a mismatch of the code and the customer workflow. Pilots provide valuable feedback that allows the CREATE development teams to address customer problems before the general release occurs.

Risk 7. Inability to anticipate and respond to the impact of rapidly changing computational and computer technologies (especially rapidly changing computer architectures and environments).

Practice: Rely on proven computational science and engineering and computational mathematics technologies to satisfy customer-defined use-cases.

Although some attributes of the implementations depend on evolving technology (especially regarding HPC hardware architectures), the customer use-cases are met with proven computational methods for the technical problems being addressed (e.g. fluid dynamics, structural analysis, …) that do not require research breakthroughs. While the scaling performance at the margins may be at risk, the basic functionality is not.

Practice: Ensure that the CREATE program maintains an awareness of the evolving state of the art in high performance computing and its implications for enhancing the performance of the CREATE applications and keeping its computational technologies modern.

Computer architectures are evolving rapidly and methods for exploiting these architectures will likely require significant modernization of existing codes and solution algorithms[23]. The CREATE program and the HCPMP do not have the resources to meet this challenge on their own. CREATE has been preparing itself to be able to rapidly adopt the solutions developed by the software divisions of the major computer chip vendors and the general High Performance Computing (HPC) community. The CREATE codes are all highly modular so that the work required to modernize the codes is minimized. In addition, senior HPCMP and CREATE staff interact regularly with DOE and NSF staff and other research organizations, and monitor progress in the field. CREATE and the HPCMP co-sponsor pilot projects with groups building computational mathematics libraries to stay abreast of recent developments and assess their impact on CREATE and DoD HPC codes.

Risk 8. Loss of DoD stakeholder and sponsor support due to frequent changes of senior DoD personnel.

Federal programs usually have stakeholders consisting of both sponsors and customers—sometimes the same organization, but not always. The personnel in these two communities change frequently, especially senior DoD and Service leaders. At one time or another, these changes have jeopardized the success and even the existence of every CREATE code team, and a few times have threatened the existence of the whole CREATE Program. As one step to cope with these changes, CREATE leverages its Boards of Directors, and continually meets with and informs new stakeholders to ensure their support.

Practice: Form and Convene the CREATE project Boards of Directors (BoDs) at least annually to help ensure that stakeholder organizations remain engaged.

As indicated above, each CREATE project has a Board of Directors composed of senior leaders (primarily Senior Executive Service or their military equivalents) of the DoD stakeholder communities within the Services. In addition to the role of ratifying the initial use-cases, these Boards:

- Provide timely advice and input on project plans
- Provide project advocacy, and provide Service and acquisition community input/views
- Provide senior customer oversight
- Reaffirm that the product use-cases remain relevant, or propose new use-cases (this also helps address Risk 6)
- Ensure that new Board members are recruited to replace those who are transferred to new assignments (so that contact with sponsors and customers is not lost)

Practice: Continually reach out to new senior and middle level members of the DoD acquisition engineering community (government and industry) to acquaint them with the potential of CREATE to improve acquisition customer outcomes. Maintain relationships with those who supported CREATE, but have moved to new responsibilities.

There must be an ongoing strategic outreach activity due to the frequent turnover of senior DoD civilian leaders and military staff during the CREATE life cycle. In general, budgets in the DoD are a zero sum game. Every new DoD leader has new ideas that are usually require starting new programs. New programs require funds that generally have to be diverted from existing programs. It is thus essential to be able to convince the new leadership that your program is more valuable than the competitors. To lose your program, you only have to lose that argument once.

Risk 9. Loss of Control of Intellectual Property Rights.

The CREATE tools are military assets designed to provide the DoD with a military competitive advantage. If the DoD cannot maintain control of the distribution of the CREATE tools, that military competitive advantage is at risk.

A business can protect its intellectual property in a number of ways, for example, with patents, copyrights, and trademarks. CREATE, as a DoD enterprise, cannot take advantage of patents without exposing sensitive information that would compromise the Government's military competitive advantage. Also, Federal employees do not automatically receive a copyright for their work products. To cope with these limitations, CREATE adopted the following three practices.

Practice: Require a Standard Software Distribution Agreement (a license for use).

A uniform distribution (license) agreement has three important benefits:
- Clearly specified restrictions on the use of the code (such as not selling, sublicensing, transferring, reverse compiling, or reverse engineering the code)
- Provides a warning that the CREATE software and associated materials are export controlled under the International Traffic in Arms Regulations (ITAR)

- Identifies the user and the intended use

Practice: Trademark the CREATE tools (protect the CREATE brand).

In the absence of patents and copyrights, CREATE has adopted the practice of trademarking its products. This practice might not seem necessary for software tools used primarily within the DoD and its contractors. However CREATE applications have been licensed to commercial companies whose business is not entirely confined to DoD contracts. This poses a greater risk that CREATE codes could be misappropriated or that results from other codes or unauthorized CREATE variants could be misattributed to CREATE. The use of a trademark identifies the CREATE software tools as government-owned and tested and provides a basis for removal of the CREATE name from unauthorized software.

Practice: Acquire the Necessary Rights in Contracts and Licenses.

Specifically ensure that all the contracts for developing CREATE software include the Defense Federal Acquisition Regulations (DFARS) clauses that grant unrestricted distribution rights to the DoD.

Like most modern software, CREATE tools make use of 3rd party applications to generate much of the code functionality. These applications range from 3rd party solvers (for example, linear equation solvers) to libraries (example, message passing) to embedded components (local grid refinement routines). The use of third party components by the CREATE software development teams is a key risk area which requires careful selection of the components not only for their technical abilities but also for their licensing obligations. A single instance of the insertion of code into CREATE tools without review and approval of the validity of the license agreement could jeopardize the ability to distribute the application, cause the Government to lose the right to use the application, and subject the Government to legal action to recover alleged "damages" for violating license restrictions. Consequently, all vendor licenses are reviewed by the CREATE legal advisors to determine if distribution of CREATE will be inhibited by any standard license restrictions, copyrights, or patents. If necessary, new licenses are negotiated or alternate software is licensed or developed internally. In addition, an audit is performed of the source code before release in order to verify thoroughly that all the terms of the respective third party licenses are acknowledged before releasing derivative or extended software. This is standard practice for the commercial software industry.

The use of contracted software development support personnel for the CREATE program poses a risk of not having unlimited Government rights to distribute the software. If the Government pays for 100% of the software development effort, CREATE insists on unlimited use rights; for software development contracts where the software has only been partially funded by the Government, CREATE receives government purpose rights. In all cases the government retains exclusive, irrevocable rights to use software developed by a contractor in accordance with Defense Federal Acquisition Regulations (www.farsite.hill.af.mil).

Risk 10. Inability to support the CREATE software users

User support is a key requirement for success. Users must have a good working knowledge of the strengths and weaknesses of the software tools, and be skilled users of the tools. They need training and support. Defects must be reported and fixed. Shortcomings in code usability must be remedied. Deficiencies in models must be identified and corrected. A responsive user support organization is essential for sustained user adoption and effective use of the CREATE tools.

Obtaining funding for user support has many challenges[24]. Senior decision makers—who control funding—can easily understand the need to explicitly fund a test or research facility (e.g. a wind tunnel) but do not as readily accept the need for sustained funding for user support for computational tools. In almost all cases, our experience is that funding for user support only becomes available after the tools have convincingly proven their value, which can take a long time, even 5 to 10 years.

Practice: Establish initial small-scale pilot projects for user support to develop effective methods for user support and to establish the utility and necessity of user support.

Summary

These practices have enabled the CREATE program to successfully manage the ten core risks associated with the five "complexities" for nearly nine fiscal years through three federal administrations, a major shift in the program "home" (from the Office of the Secretary of Defense to the Army Corps of Engineers) that led to major changes in financial and contracting procedures, and continual personnel changes and reorganizations within sponsoring and customer organizations.

While all of the practices described above have been important during the life of CREATE, some summary statements can be made about them:

- Implement all of the Software Management Principles in Table 1. Leaving out even one can jeopardize the success of a program.
- Understand the complexities of your organization (e.g. Table 2) and make the effort to identify key risks and possible mitigations up front
- Do not ignore programmatic risks like program sponsorship and institutional turmoil just because they seem intractable
- Release your software frequently (at least annually) to garner the input and support of your customers; the releases should offer something of substance
- Technically competent leadership at the program and development team level is a crucial success factor for technical software development teams
- Do not underestimate the possible impact of an ever tightening security environment on distributed development teams and customers
- Managing IP rights, especially in today's world of open source software components, is critical to the right to distribute your software

The Software Project Management Principles (Table 1) apply to almost all programs that develop physics-based computational engineering software. The CREATE practices were specifically derived for the DoD environment. However, we believe that most of the CREATE practices will be useful for any program developing and deploying computational engineering software with distributed, non-collocated teams.

Acknowledgments

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